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Rogers et al.

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(54) **CHARACTERIZING DIMENSIONS OF STRUCTURES VIA SCANNING PROBE MICROSCOPY**

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(58) **Field of Classification Search**
None
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

5,418,363 A * 5/1995 Elings et al. 850/1
5,508,528 A * 4/1996 Mulkens G03F 7/70058
250/492.1
5,523,700 A * 6/1996 Williams et al. 324/765
5,581,345 A * 12/1996 Oki G01B 11/0608
356/4.01

5,591,659 A * 1/1997 Ema H01L 27/105
257/E21.646
5,773,824 A * 6/1998 Flecha et al. 850/1
5,825,670 A * 10/1998 Chernoff et al. 702/85
5,898,106 A * 4/1999 Babcock et al. 73/105
5,902,928 A * 5/1999 Chen et al. 73/105
6,000,281 A * 12/1999 Burke 73/105
6,016,684 A * 1/2000 Scheer B82Y 35/00
250/252.1
6,128,209 A * 10/2000 Kuroki G11C 5/063
257/296
6,144,028 A * 11/2000 Kley 250/234
6,225,179 B1 * 5/2001 Yokoyama H01L 21/76202
257/E21.552
6,229,138 B1 * 5/2001 Kley 250/234
6,232,597 B1 * 5/2001 Kley 250/234
6,242,734 B1 * 6/2001 Kley 250/234
6,246,255 B1 * 6/2001 Takizawa G06F 13/4086
326/10
6,265,711 B1 * 7/2001 Kley 250/234
6,279,389 B1 * 8/2001 Adderton et al. 73/105
6,281,491 B1 * 8/2001 Kley 250/234
6,339,217 B1 * 1/2002 Kley 250/216
6,354,133 B1 * 3/2002 Yedur et al. 73/1.89
6,392,229 B1 * 5/2002 Dana et al. 850/33
6,408,123 B1 * 6/2002 Kuroda B82Y 20/00
359/368
6,475,598 B1 * 11/2002 Naoe B82Y 15/00
428/141
6,503,447 B1 * 1/2003 Mondjian B01D 53/885
250/437
6,515,277 B1 * 2/2003 Kley 250/234
6,517,776 B1 * 2/2003 Rodgers B65B 55/08
118/317

(Continued)

FOREIGN PATENT DOCUMENTS

WO WO 2004053928 A2 * 6/2004
WO WO 2006135375 A2 * 12/2006

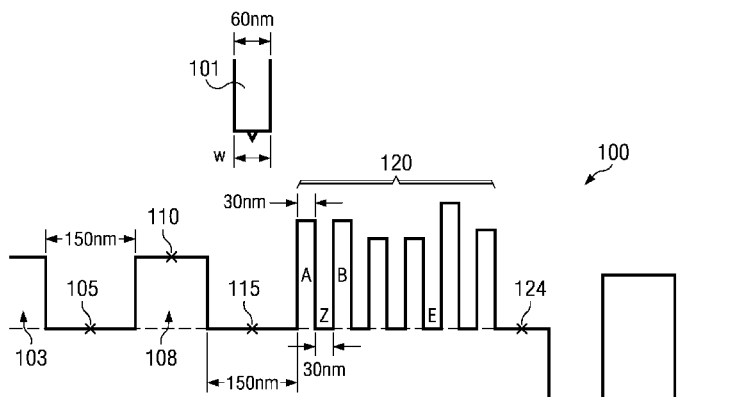
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(57) **ABSTRACT**

A method comprising characterizing the dimensions of structures on a semiconductor device having dimensions less than approximately 100 nanometers (nm) using one of scanning probe microscopy (SPM) or profilometry.

21 Claims, 1 Drawing Sheet



(56)

References Cited

U.S. PATENT DOCUMENTS

6,646,278 B1 *	11/2003	Schwarz	.....	B05D 3/067 250/504 R	2003/0215670 A1 *	11/2003	Takahashi	.....	G11B 5/7305 428/842
6,772,620 B1 *	8/2004	Poris	.....	H01L 21/3212 250/252.1	2003/0233870 A1 *	12/2003	Mancevski	.....	73/105
6,818,277 B2 *	11/2004	Takahashi	.....	G11B 5/7305 428/842.1	2003/0237064 A1 *	12/2003	White	.....	G06F 17/5068 716/136
6,856,145 B2 *	2/2005	Pelz et al.	.....	324/663	2005/0056783 A1 *	3/2005	Kley	.....	250/309
7,190,512 B2 *	3/2007	Sakai et al.	.....	359/350	2005/0092907 A1 *	5/2005	West	.....	G01Q 10/045 250/234
7,205,211 B2 *	4/2007	Aspar	.....	B81C 1/0038 257/E21.122	2005/0104015 A1 *	5/2005	Wedowski	.....	B08B 7/0035 250/504 R
7,335,881 B2 *	2/2008	Tanaka et al.	.....	250/311	2005/0124138 A1 *	6/2005	Aspar	.....	B81C 1/0038 438/459
7,381,950 B2 *	6/2008	Rogers	.....	G01N 23/225 250/307	2005/0173633 A1 *	8/2005	Tanaka et al.	.....	250/311
2002/0158197 A1 *	10/2002	Dana	.....	G03F 7/0633 250/306	2005/0242379 A1 *	11/2005	Sakai	.....	B08B 7/0035 257/288
2003/0059549 A1 *	3/2003	Morrow	.....	C09D 1/00 250/504 R	2005/0283335 A1 *	12/2005	Banke et al.	.....	702/170
2003/0182993 A1 *	10/2003	Hantschel	.....	B82Y 35/00 73/105	2006/0071164 A1 *	4/2006	Rogers et al.	.....	250/309
					2006/0192158 A1 *	8/2006	Wedowski	.....	B08B 7/0035 250/504 R
					2007/0207318 A1 *	9/2007	Jin	.....	B81C 1/00103 428/408

* cited by examiner

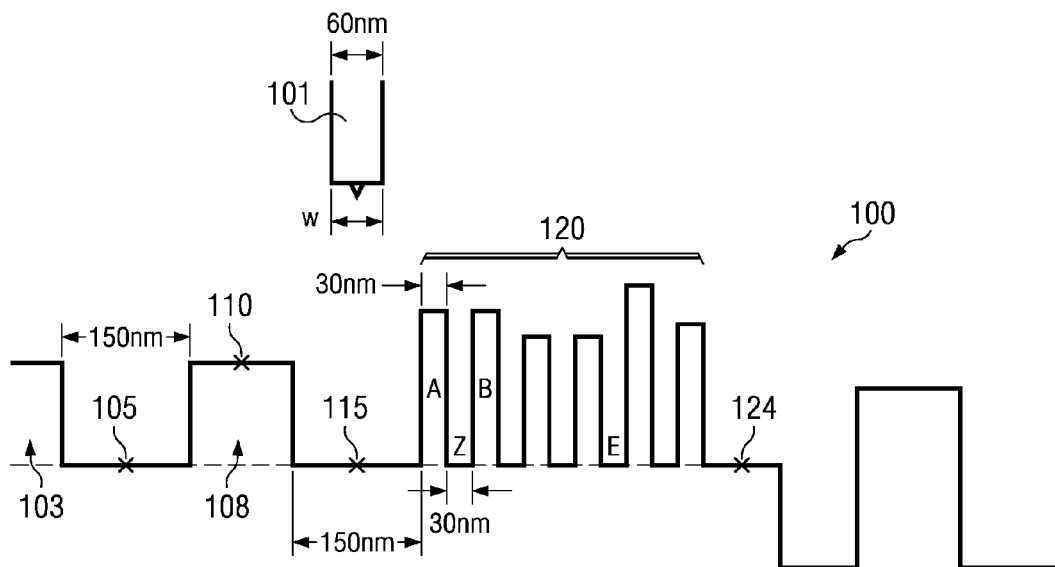


FIG. 1a

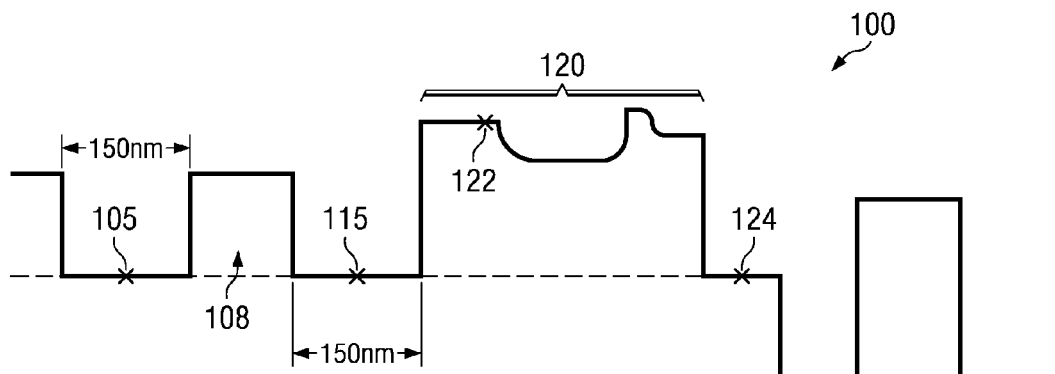


FIG. 1b

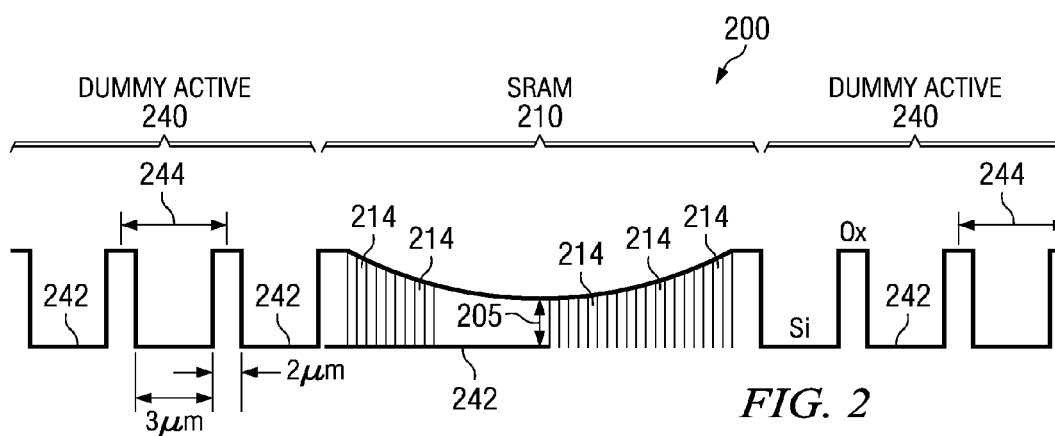


FIG. 2

CHARACTERIZING DIMENSIONS OF STRUCTURES VIA SCANNING PROBE MICROSCOPY

This is a division of application Ser. No. 10/953,629, filed
Sep. 29, 2004.

BACKGROUND

Integrated circuits are fabricated on the surface of a semiconductor wafer in layers, and later singulated into individual semiconductor devices, or “dies.” Many fabrication processes are repeated numerous times, constructing layer after layer until fabrication is complete. Metal layers, which typically increase in number as device complexity increases, include patterns of conductive material that are vertically insulated from one another by alternating layers of insulating material. Conductive traces are also separated within each layer by an insulating, or dielectric, material. Vertical, conductive tunnels called “vias” typically pass through insulating layers to form conductive pathways between adjacent conductive patterns.

Advancements in the size and speed of semiconductor devices continue to occur in order to meet consumer and competitive demands. The reduction in size of device features that accompanies such advancements also pushes innovation in the capabilities of manufacturing tools. Particularly, measurement techniques and tools must be able to accurately detect smaller and smaller dimensions.

SUMMARY

The problems noted above are solved in large part by a method for characterizing dimensions of structures by way of scanning probe microscopy. An exemplary embodiment comprises a method comprising characterizing the dimensions of structures on a semiconductor device having dimensions less than approximately 100 nanometers (nm) using one of scanning probe microscopy (SPM) or profilometry. Another exemplary embodiment comprises a method comprising establishing a reference position on a semiconductor device using one of SPM or profilometry, establishing a target position on an upper surface of the structure using one of SPM or profilometry, said upper surface facing away from the device. The method further comprises determining the difference between the reference position and the target position, wherein the reference position and the portion of the device coupled to the structure are coplanar.

BRIEF DESCRIPTION OF THE DRAWINGS

For a detailed description of exemplary embodiments of the invention, reference will now be made to the accompanying drawings in which:

FIG. 1a shows a cross-sectional side view of a semiconductor device surface comprising multiple sub-100 nm structures, in accordance with embodiment of the invention;

FIG. 1b shows the configuration of FIG. 1a, wherein the surfaces of the sub-100 nm structures are shown as a continuous contour, in accordance with embodiments of the invention; and

FIG. 2 shows a cross-sectional side view of a SRAM array on a surface of a semiconductor device, in accordance with embodiments of the invention.

NOTATION AND NOMENCLATURE

Certain terms are used throughout the following description and claims to refer to particular system components. As

one skilled in the art will appreciate, companies may refer to a component by different names. This document does not intend to distinguish between components that differ in name but not function. In the following discussion and in the claims, the terms “including” and “comprising” are used in an open-ended fashion, and thus should be interpreted to mean “including, but not limited to” Also, the term “couple” or “couples” is intended to mean either an indirect or direct electrical connection. Thus, if a first device couples to a second device, that connection may be through a direct electrical connection, or through an indirect electrical connection via other devices and connections.

The term “integrated circuit” or “IC” refers to a set of electronic components and their interconnections (internal electrical circuit elements, collectively) that are patterned on the surface of a microchip. The term “semiconductor device” refers generically to an integrated circuit (IC). The term “die” (“dies” for plural) refers generically to an integrated circuit or semiconductor device, which may be a portion of a wafer, in various stages of completion, including the underlying semiconductor substrate, insulating materials, and all circuitry patterned thereon. The term “trench” refers generically to any feature that adds a dimension among the materials forming a die. To the extent any term is not specifically defined in this specification, the intent is that the term be given its plain and ordinary meaning.

DETAILED DESCRIPTION

The following discussion is directed to various embodiments of the invention. Although one or more of these embodiments may be preferred, the embodiments disclosed should not be interpreted, or otherwise used, as limiting the scope of the disclosure, including the claims. In addition, one skilled in the art will understand that the following description has broad application, and the discussion of any embodiment is meant only to be exemplary of that embodiment, and not intended to intimate that the scope of the disclosure, including the claims, is limited to that embodiment.

Provided herein are methods of characterizing the dimensions of structures on semiconductor devices, such as integrated circuits (IC), via scanning probe microscopy (SPM) and/or profilometry, where a device comprises structures having dimensions less than about 100 nanometers. While the measurement techniques disclosed herein are primarily discussed in context of SPM, any technique, such as profilometry, also may be used. In accordance with various embodiments, the dimensions of structures are characterized by reckoning the distance from a probe of the SPM at a reference position to the probe of the SPM at a second position. The reference position may be represented by a single measurement, an average of multiple measurements, or a range of measurements taken at one or more positions designed to be in the same plane.

SPM permits the imaging and measuring of surfaces on a fine scale (e.g., on the scale of several microns), even to the level of molecules and/or groups of atoms. A variety of SPM techniques exist and may be used in context of the subject matter presented below. Such techniques include, among others, atomic force microscopy (AFM), scanning tunneling microscopy (STM), and near-field scanning optical microscopy (NSOM). Specifically, AFM measures the interaction force between a tip of the probe and a surface that is to be measured. The tip may be dragged across the surface, or may vibrate as it moves. The interaction force will depend on the nature of the sample, the probe tip and the distance therebetween. STM measures a weak electrical current flowing

between tip and sample as they are held apart from each other. NSOM scans a light source that is located in substantially close proximity to the sample. Detection of this light energy is used to form images or measurements. NSOM can provide resolution below that of the conventional light microscope. The scope of disclosure is not limited to these types of SPM. SPM is described in greater detail in U.S. Pat. No. 5,371,365, which is incorporated herein by reference.

FIG. 1a illustrates an example of a cross-sectional view of a surface 100 exhibiting structures of varying dimensions. A SPM probe 101 may be employed to characterize the dimensions of the structures on the surface 100. The height of structure 108, for example, may be characterized by reckoning the distance from a SPM probe measurement taken at position 105 to a SPM probe measurement taken at a second position 110. The probe 101, in this illustration having a width of 60 nm, may be placed at position 105 between structures 103 and 108 as the distance between structures 103 and 108 is 150 nm.

The probe 101 may also be employed to characterize the dimensions of a series of structures 120 having dimensions smaller than the probe 101. The structures in the series 120, such as structure A and structure B, are 30 nm wide and divided by distances of 30 nm. Thus, the 60 nm probe 101 will not reach position Z, for example, in order to characterize the dimensions of the structures in the series 120. In embodiments, the SPM probe 101 scans the surface 100 in order to create a profile of the structures. Where the probe 101 will not reach certain positions, such as position Z among the series of structures 120 having dimensions smaller than the probe, it may scan the contour of the series 120 in order to create a profile of the contour of the series 120. Such a profile of the surface 100 is illustrated in FIG. 1b.

FIG. 1b illustrates what may result from a scan of the surface 100 in FIG. 1a with an SPM probe. The probe scan takes measurements at positions it may reach to create an outline of the structures on the surface 100. Thus, a scan of the series of structures 120 outlines the contour 122 of the series 120.

The dimensions of the structures in the series 120 may be characterized by establishing a reference position. The surface 100 may be designed such that positions 115, Z, and E, for example, are all designed to be in the same plane. In such a case, position 115 may be a reference position for characterizing the dimensions, e.g. heights, of structures in series 120 where a larger probe 101 will not reach. The reference position may comprise any position having dimensions that permit access by the SPM probe.

Thus, in various embodiments, by establishing a reference position, a SPM probe may characterize the dimensions of structures, including sub-100 nm structures, on a surface 100 that includes structures having dimensions smaller than the probe 101. Measurements for such characterizations may be accomplished independent of the size of the SPM probe. Such SPM probes may comprise a tip size less than or equal to about 1000 nm in diameter. The probe may scan a surface 100 to outline the contour 122 of the surface 100, such as illustrated by FIGS. 1a and 1b. Positions 105 and 115, accessible by probe 101 and designed to be in the same plane as positions not accessible by probe, such as position Z and position E, may be used to establish a reference position. In some embodiments, the reference position comprises an average of measurements at positions designed to be in the same plane. For example, where positions 105, 115, and 124 are designed to be in the same plane, the reference position for characterizing the dimensions of structures not accessible by probe

may be established by averaging probe measurements taken at positions 105, 115, and 124.

The various heights of structures among the series 120 may be characterized by reckoning the distance from the height of the probe at the established reference position to the height of the probe at the various positions along the contour 122.

In some embodiments, characterizing the dimensions of structures comprises measuring step height in an SRAM array. In other embodiments, structures that may be characterized by the method provided comprise DRAM, Logic, inductors, input/output structures, or combinations thereof. FIG. 2 illustrates a surface 200 of a cross-sectional view of an SRAM array 210 on a section of a semiconductor device, which includes sub-100 nm structures, and the surrounding dummy active region 240. The field oxide of the SRAM 210 may contain many structures with dimensions smaller than the smallest SPM probe, e.g., 10 nm structures 214. In this example, a distance 244 between at least some oxides may be approximately 3 micrometers.

The step height 205 of the SRAM may be defined as the difference between the height of a SPM probe when scanning the surface 242 of the dummy active region 240, and the height of the SPM probe when scanning the surface contour of the SRAM 210 field oxide. The SPM probe may scan the surface of the dummy active region 240 in order to establish the height of the SPM probe at the surface of the dummy active 242 as the reference position. The device may be designed such that the base of the SRAM is the same height as the surface of the dummy active. The SPM probe may also scan the surface of the SRAM 210 in order to outline the contour of the structures 214 of the field oxide. The scan of the contour of the field oxide region may capture variations in the height of the structures 214.

The difference between height of the SPM probe at the reference position(s) 242 and the height(s) of the SPM probe along the contour of the SRAM 210 and its structures 214 may provide the step height 205 of the SRAM 210. In addition, such characterization may indicate the range of heights of structures 214 in the SRAM 210. In some embodiments, measuring the height of the SPM probe at one or more positions on the dummy active 242 establishes a reference position or average reference position. In other embodiments, establishing a reference position at multiple points on a wafer may be used to indicate the variation in step height across a wafer.

In various embodiments, the method provided may be employed to characterize the dimensions of structures on a semiconductor device comprising sub-100 nm structures via SPM in less than or equal to about 1 hour. Specifically, the SPM probe is able to scan the surface contour of the SRAM 210 without measuring the SRAM step height between each oxide structure. That is, instead of making several time-consuming measurements to repeatedly determine step height, only a few measurements are made and the step height is thereafter determined by calculation. Thus, in some situations, using SPM to characterize the dimensions of structures on a device comprising sub-100 nm structures may require less than 20 seconds.

While various embodiments of the invention have been shown and described, modifications thereof can be made by one skilled in the art without departing from the spirit and teachings of the invention. The techniques disclosed herein may be applied to any semiconductor device, such as an integrated circuit. The embodiments described herein are exemplary only, and are not intended to be limiting. Equivalent techniques and ingredients may be substituted for those shown, and other changes can be made within the scope of the

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present invention as defined by the appended claims. Many variations and modifications of the invention disclosed herein are possible and are within the scope of the invention. Accordingly, the scope of protection is not limited by the description set out above, but is only limited by the claims which follow, that scope including all equivalents of the subject matter of the claims.

What is claimed is:

1. A method of characterizing a structure on a semiconductor device, comprising:

establishing a reference position on the device using one of scanning probe microscopy (SPM) or profilometry; establishing a target position on an upper surface of the structure using the one of SPM or profilometry, the upper surface being located further away from the device than the location of the reference position; and determining a difference between the reference position and the target position, the difference defining a physical height of the structure;

wherein the reference position and the portion of the device coupled to the structure are coplanar, and further wherein at least one additional structure separates the reference position from the structure being characterized.

2. The method of claim **1** wherein using SPM comprises using a technique selected from a group consisting of atomic force microscopy (AFM), scanning tunneling microscopy (STM), and near-field scanning optical microscopy (NSOM).

3. The method of claim **1** wherein establishing the target position on the upper surface of the structure comprises using a structure having dimensions between approximately 0.2 nanometers and 100 nanometers.

4. The method of claim **1** wherein establishing the reference position comprises determining an average of measurements at multiple positions on a single plane.

5. The method of claim **1** wherein establishing the target position on the upper surface of the structure comprises using a structure selected from a group consisting of static random access memory (SRAM) arrays, dynamic random access memory (DRAM) arrays, inductors, input/output structures, and combinations thereof.

6. The method of claim **1** wherein determining the difference occurs in less than or equal to approximately twenty seconds.

7. The method of claim **1** wherein determining the difference comprises determining step height in a static random access memory (SRAM) array.

8. The method of claim **1** wherein the reference position comprises any position having dimensions that permit access by a probe of the one of SPM or profilometry.

9. The method of claim **1** wherein a space between the structure and the at least one additional structure is less than a width of a probe of the one of SPM or profilometry.

10. A method of characterizing a set of structures on a semiconductor device, comprising:

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establishing a reference position on the device using one of scanning probe microscopy (SPM) or profilometry; and characterizing the set of structures by repeatedly performing the method comprising:

establishing a target position on an upper surface of one of the set of structures using the one of SPM or profilometry, said upper surface being located further away from the device than the location of the reference position; and

determining a difference between the reference position and the target position, the difference defining a physical height of the structure;

wherein the reference position and the portion of the device coupled to the structure are coplanar.

11. The method of claim **10** wherein using SPM comprises using a technique selected from a group consisting of atomic force microscopy (AFM), scanning tunneling microscopy (STM), and near-field scanning optical microscopy (NSOM).

12. The method of claim **10** wherein establishing the target position on the upper surface of the one of the set of structures comprises using a structure having dimensions between approximately 0.2 nanometers and 100 nanometers.

13. The method of claim **10** wherein establishing the reference position comprises determining an average of measurements at multiple positions on a single plane.

14. The method of claim **10** wherein establishing the target position on the upper surface of the one of the set of structures comprises using a structure selected from a group consisting of static random access memory (SRAM) arrays, dynamic random access memory (DRAM) arrays, inductors, input/output structures, and combinations thereof.

15. The method of claim **10** wherein determining the difference occurs in less than or equal to approximately twenty seconds.

16. The method of claim **10** wherein determining the difference comprises determining step height in a static random access memory (SRAM) array.

17. The method of claim **10** wherein the reference position comprises any position having dimensions that permit access by a probe of the one of SPM or profilometry.

18. The method of claim **10** wherein a space between a first of the one of the set of structures and a second of the one of the set of structures is less than a width of a probe of the one of SPM or profilometry.

19. The method of claim **10** wherein a probe of the one of SPM or profilometry scans the upper surface of each of the set of structures without the probe lifting off the upper surface of the each of the set of structures.

20. The method of claim **1** wherein the reference position is at a dummy active and the target position is at a SRAM field oxide.

21. The method of claim **10** wherein the reference position is at a dummy active and the target position is at a SRAM field oxide.

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